EXPERIMENTAL AND THEORETICAL STUDIES OF WIND-WAVE GENERATION AND EVOLUTION

Norden E. Huang

Code 971
NASA Goddard Space Flight Center
Greenbelt, MD 20771
phone: (301) 286-8879 fax: (301) 286-0240 email:
norden@neptune.gsfc.nasa.gov

Mail Stop 104-44
Department of Engineering Science
California Institute of Technology
Pasadena, CA 91125
Phone: (626) 395-3389 fax: (626) 795-9839 email: norden@cco.caltech.edu

Award # : NOOO14-95-F-0056

LONG-TERM GOAL

The long term goal is to investigate the generation and the nonlinear evolution of the wind wave field. Specifically, we want to know the predominate generation mechanism, their directional distribution in the initial stage, how do they propagate, and what is its role in determining the surface stress.

SCIENTIFIC OBJECTIVES

I wish to establish the mechanisms of wind wave generation: whether the Miles (1957) instability mechanism or the Phillips (1957) resonant mechanism is more relevant. There is a long standing controversy of the wind wave generation mechanism: Is it the shear instability or is it the resonant pressure pulsation of the wind. Once the waves are generated, I want to establish the process of their evolution: whether the growth of the waves in height and length is a continuous process or a discrete one. Under a steady off-shore wind, the process should be a stationary process. Then, the classical kinematic wave conservation theory would predict the frequency of the wave field to be constant. Yet the observed wind wave spectra all show a definite trend of frequency downshift. And, finally, I want to establish the role of waves in determining the surface stress.

APPROACH

We adopted a multi-directional attach on the problems:

For the wind wave generation mechanism, I re-examined all the directional wind-wave data collected over the SWADE area. Based on the data we find that the directions of wind wave propagation are not aligned with the local wind. The sum of the data is not inconsistent with the Phillips resonant theory.

For the wave evolution study, we relied on laboratory experiments and detailed data analysis. For this particular problem, we have developed a special data analysis method: the Empirical Mode Decomposition (EMD) and the Hilbert Spectral Analysis (HAS) (Hunag, et al., 1997), which give us a detailed view for any nonstationary and nonlinear time series. The analysis reveals that the wave evolution process is discrete rather than continuous, local rather than global.

WORK COMPLETED

Analysis of the field data from three historical flights and a recent one over the SWADE area is finished. The directional distribution of the wind-wave field shows that the directions of wind waves propagation are always non-aligned with the local mean wind direction. The deviation angles are in agreement with those predicted by Phillips resonant generation theory. Yet the wind waves are not always symmetric with respect to the wind direction as predicted by the theory (Huang, 1997).

The first round of laboratory experiment for the nonlinear wave evolution is completed (Huang, et al., 1996). Additional experiments are being planned to catch the detailed flow field under the waves to see what effects of the wave had on the fluid particle during the fusion process.

A data analysis tool has been established to study the nonstationary and nonlinear data. This method could be the most important result of the whole study.

RESULTS

Two types of results are presented as follows: The first is the directional wind wave distribution. The second part illustrates the wave fusion process.

Figure 1 shows the directional wave spectrum under an off-shore wind with a fetch of 17 km. The mean wind direction is from 350 degree north. The wave energy, however, are concentrated in the two asymmetric off wind directions. Though the angles sustained by the waves agree with the values predicted by Phillips's Resonant theory, but the asymmetric pattern is not predicted by Phillips.

Figure 2 shows the fusion of two waves. The to panel gives the data and the phase variation. Fusion occurs where the phase jumped by 2π. To illustration the fusion process in time, the data is plotted again with the initial sinusoidal wave at the station nearest to the wave maker in dotted line. The fusion data is in solid line. The profile of the waves show a clear two-to-one fusion.

Fig.1 Directional wind wave spectrum off Long Island, New York

The mean wind direction is from 355^{0} N

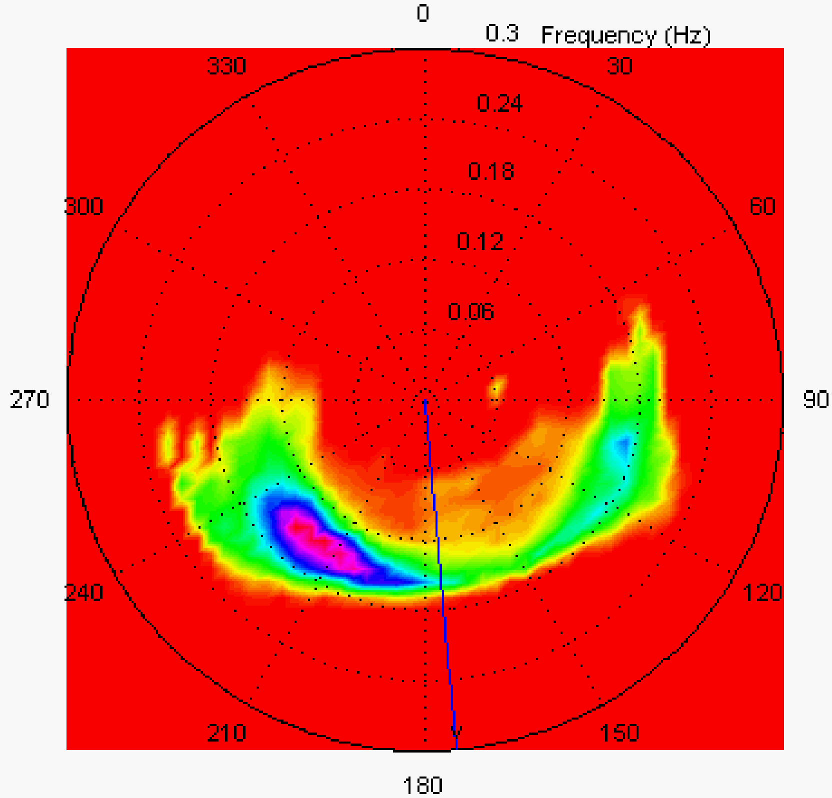
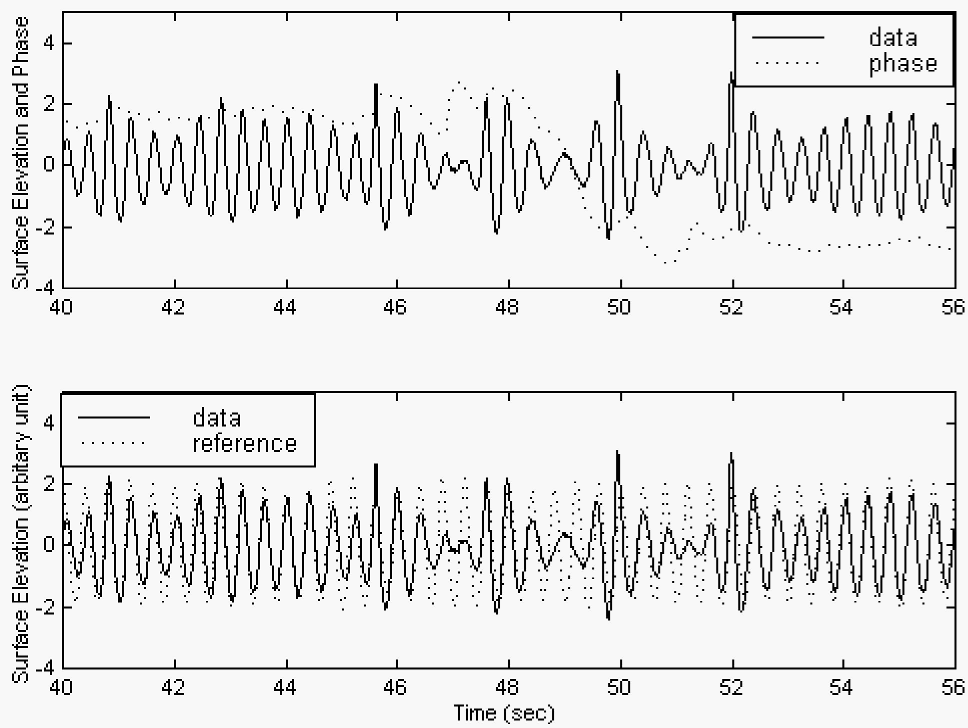


Fig.2 Detail of wave fusion, at the fusion point, the phase jump is exact 2π



IMPACT/APPLICATION

Based on our results, we can draw the following implications:

1. The non-alignment of the wind waves with the local wind direction may imply the surface stress field is a tensor quantity (Friehe, et al., 1997). Therefore, the surface stress field can no longer be parameterized by a single scalar drag coefficient.

2. The fusion of waves implies that the basic assumption of the classic wave theory of gradual change of phase function in a wave field is unattainable. If so, then what should we propose in its place?

3. The applications of the Empirical Mode Decomposition (EMD) and the Hilbert Spectral Analysis (HAS) are the most far-fetching. The method has been patent by NASA. Currently, we are applying it to the submarine design, sonar detection of submarines, earthquake and building response, arrhythmia of the heart beat, brain waves, and possible non-destructive testing of structure damage.

TRANSITIONS

The Empirical Mode Decomposition (EMD) and the Hilbert Spectral Analysis (HAS) has been transferred to the Harvard Medical School for detection of heart problem and the diagnosis of sleep apnea. it has also transferred to the Naval Surface Warfare Center to help resolve some submarine design and detection problem. Some scientists in NSWC have also used the method to detect the nonlinear vibrations of the welding and milling processes. Currently, I am on a NASA fellowship at the California Institute of Technology to study the potential of using this method for earthquake signal and building response analysis.

A patent has been filed by NASA on the basic method and its applications to the geophysical data. Additional patents are under preparation for filtering, image analysis, bio-medical applications, and non-destructive structural damage detection.

RELATED PROJECTS

Three projects are closed related to the present efforts:

1. The coastal wave modeling
2. The earthquake signal analysis
3. The analysis of the submarine wake flow field

REFERENCES

Friehe, C., G. L. Geernaert, K. F. Reider, J. A. Smith, J. P. Giovanangeli, and N. E. Huang, 1997: Wind, Stress and Wave Directions. *Wind Drag over the Ocean, Cambridge University Press. (to appear)*

Huang, N. E., S. R. Long, and Z. Shen, 1996: The Mechanism for frequency downshift in nonlinear wave evolution. *Advances in Applied Mechanics*, 32, 59-117.

Huang, N. E., Z. Shen, S. R. Long, etVIal., 1997: The empirical mode decomposition and Hilbert spectrum for nonlinear and nonstationary time series analysis Proc. Roy. Soc. Lond., (in press).

Huang, N. E., 1997: A review of coastal wave modeling: The physical and mathematical problems. *Advances in Coastal Engineering*, (in press)

Miles, J. W., 1957: On the generation of surface waves by shear flows. *J. Fluid Mech*., 3, 185-204.

Phillips, O. M., 1957: On the generation of waves by turbulence wind. *J. Fluid Mech*., 2, 417-445.